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Volatility Spillovers and Linkages in Asian Stock Markets

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Abstract

This paper examines the pattern of volatility transfers in Asian stock markets in the context of deepening global as well as regional financial integration. Diebold-Yilmaz spillover indexes are computed for the weekly return volatilities based on daily benchmark stock indexes of US, UK and ten Asian countries. We found the strengthening of overall volatility spillovers is not a temporary surge during the crisis but persisted after the crisis, even as the economic environment remained uncertain. We also provide evidence the susceptibility of individual Asian stock markets to inward volatility transfers is linked to its degree of openness. The observed general increase in outward volatility transfers since the onset of the crisis suggests the Asian bourses are becoming more important emitters of financial shocks. As for volatility linkages between Asian bourses and major stock markets, we found using rolling regressions a general pattern of relative dominance of the US stock market over the Japanese and Chinese bourses. However, the level of influence on Asian stock markets from the Chinese bourse in terms of volatility linkages, has risen to that of Japan but remains lower than that of the US.

JEL Classification: G15, F36

Keywords: Asian stock markets, return volatility, volatility spillovers

1 Introduction

Cross-border linkages among national stock markets have been strengthening over time aided by free capital flows and the advancement in information technology. The use of electronic trading that reduces cost and increases the speed of international financial transactions have helped to advance this trend. Additionally, the deregulation of equity markets and liberalization of financial accounts in emerging market economies increase their connectedness with world markets. A case in point is China where the partial opening of stock markets to foreign participation and the gradual shift towards market-determined exchange rates result in greater integration of Chinese equity markets into the global financial system. This is evidenced by sharp falls in Asian bourses following the plunge in Chinese stock prices due to the announcement a change in the renminbi exchange rate regime on 24th August 2015. More recently, on 6th January 2016, the suspension of trading of Chinese stocks triggered a widespread correction in world equity markets.

As countries become more financial integrated, cross-border transmission of equity market shocks rises in tandem. In fact extensive cross-border financial linkages and the rapid growth in gross international assets lead to tighter co-movement of gross capital flows, asset prices and credit growth across countries (Rey, 2013). The presence of a strong global dimension which is driven by the level of international investors' risk aversion can be identified in these financial cycles. As for channels of transmission, financial market spillovers across countries could take place through financial as well as trade linkages (IMF, 2016). The presence of common investors across national markets means they can propagate shocks through portfolio rebalancing. Real-economy linkages could also generate financial market spillovers. For instance, news about economic fundamentals of an economy will not only affect its domestic equity market but also the stock prices of foreign firms exporting to or with subsidiaries in that economy.

Even though deeper financial integration can bring about significant economic benefits such as portfolio diversification for international investors and risk sharing across countries, exposing domestic financial markets to the international financial transactions can thus be accompanied by higher risks of financial instability.¹ An increased understanding of the interactions among national stock markets is helpful not only to international investors for portfolio diversification purposes, but also to policymakers with financial stability concerns. Indeed, the recurrence of financial and currency crises has raised the question of whether developing countries should continue to promote financial openness since the increased vulnerability to external shocks will tend to weaken the impact of financial deepening on growth (Rousseau and Wachtel, 2011).

In the case of Asia, the level of financial openness varies widely across different groups of economies. Japan, Hong Kong and Singapore are fully integrated with global markets as is expected of their status as financial centers. At the other extreme, China is making efforts to gradually open its financial account. Meanwhile, the vast majority of countries in Asia have intermediate levels of financial openness. Borenstein and Loungani (2011) found that financial linkages between Asia and the rest of the world are stronger than those within the region. However, strong investment activities and high savings in Asia over the past decade have led to intra-regional financial flows² growing at a faster clip than regional GDP. Indeed, efforts at strengthening financial cooperation and integration are ongoing in the region. For instance, ASEAN countries have taken initiatives to integrate their capital markets that include efforts to facilitate cross-listing of securities and cross-border settlement.

¹ The tradeoffs between costs and benefits of financial integration is still an ongoing debate, see *inter alia* Kose et al. (2006).

² Intra-regional flows account for about 20 to 30 percent of private cross-border portfolio investment and bank claims. Moreover, intra-regional allocations for the official sector for which there is no published data is also likely to have increased, see IMF (2015).

How has the deepening of global as well as regional financial integration affected the transmission of financial shocks in Asia?

This paper uses the spillover indexes proposed in Diebold and Yilmaz (2009, 2012) to obtain an overall picture of shock transmissions in the Asian stock markets and investigates how this evolves over time. For instance, we ascertain whether the rise in volatility transfers in Asian bourses is a temporary surge due to contagion during crisis or that it reflects a more permanent increase in volatility transmissions. In terms of country coverage, we focus on the benchmark indices of the following ten Asian economies, namely China, Hong Kong, Indonesia, Japan, Korea, Malaysia, the Philippines, Singapore, Taiwan and Thailand. The US and UK benchmark indices, S&P500 and FTSE100 respectively, are also included in the analysis to account for extra-regional influences.

Of the other studies that apply the same methodology, Guimaraes-Filho and Hong (2016) which examines how linkages in asset returns and volatilities in Asia vary over time, is the closest to our paper. Nevertheless, there are three key differences between the two papers. Firstly, even though the raw data for the local currency indexes used in our study are of daily frequency, we examine spillovers of volatility at a lower frequency. Specifically, we use weekly instead of daily return volatility derived from daily stock index data to compute the spillover indexes. Unlike daily volatility, the analysis of transmission of weekly volatility does not suffer complications from markets being in different time zones. Moreover, weekly volatility are relatively less noisy and are not affected by day-of-week effects. To the extent that national authorities are also concerned about fluctuations beyond short term daily movements, it is useful to conduct the analysis on weekly volatilities to see if the qualitative results still hold at a lower

frequency. After all, it is generally recognized that empirical findings are affected when different sampling frequencies are used (Manning, 2002).

Another key differentiation between our study and that of Guimaraes-Filho and Hong (2016) is the latter focuses on net spillovers which is the difference between volatility shocks transmitted to and volatility shocks transmitted from other markets. By contrast, we examine in this paper the levels of inward volatility transfers separately from outward volatility transfers and how they vary across individual Asian bourses. In this way, we could provide evidence that the susceptibility of an individual Asian stock market to inward volatility shocks transmission from other markets is linked to its degree of openness.

A third difference is we extend our analysis beyond Diebold and Yilmaz spillover indexes to capture dynamically both the direct and indirect effects of major stock market volatilities on individual Asian stock market volatilities. To this end, rolling regressions are used to determine the relative influence of the financial shocks originating from the major stock markets of US, Japan and China. In view of recent studies showing greater sensitivity of Asian bourses to China's stock price fluctuations, we investigate whether the pole of influence has shifted between the US, Japanese and Chinese stock markets in terms of return volatilities. To preview the results, we found the level of influence on Asian stock markets from the Chinese bourse, in terms of volatility linkages, has risen to that from the Japanese bourse but remains lower than that from the US stock market.

The rest of this paper is organized as follows. The next section provides an overview of key methodology approaches in related literature, focusing on the Diebold-Yilmaz (2012) technique for measuring the extent of spillovers in return volatilities. An analysis of the spillover indexes computed for the Asian bourses is presented in Section 3. This is followed by Section 4 that

investigates the dynamics of the relative dominance of major stock markets in the individual Asian bourses. Section 5 concludes with a summary.

2 Methodology of Diebold-Yilmaz Spillover Indexes

Empirical studies of linkages among the Asian bourses³ is part of the vast literature on the interdependence of national stock markets. A strand of the literature investigates the degree of co-movement of Asian stock returns as this reflects the level of financial integration in the region. In particular, cointegration analysis are applied to log of stock price indexes to test for the presence or otherwise of long-run relationships among the Asian stock market indexes. For instance, Yang et al. (2003) found cointegration holds for the stock market indexes of US, Japan and ten other Asian economies. By contrast, the study by Huyghebaert and Wang (2010) revealed an absence of long-run equilibrium relationship among the Asian stock indices. The mixed results obtained in these and other studies could plausibly be explained by the different time periods under review as well as differing research methodologies adopted.

A popular approach to examine the transmission of stock return volatility across markets is to adopt the VAR-BEKK framework. The application of this technique requires special variance structures in the multivariate GARCH models. Focusing on Asia-Pacific markets, Burdekin and Siklos (2012) showed using dynamic conditional correlations that co-movement accelerated after the onset of the 2007 global financial crisis. In another study, Chuang et al. (2007) investigated the pairwise interdependence of volatility in six Asian stock markets by first extracting conditional variances through a VAR-BEKK framework and then performing variance decomposition. The

³ Most studies focused on stock markets rather than bond markets as Asian bourses are more developed than regional bond markets.

authors provided evidence that the Asian bourses were much influenced by volatility in the Japanese stock market.

Diebold and Yilmaz (2009, 2012) proposed a new framework for measuring spillovers across asset markets that uses the decompositions from a vector autoregression (VAR) model. In the earlier paper, forecast error variances were decomposed through Cholesky factor identification to orthogonalize the shocks. This technique was applied to study the connectedness across global stock markets including nine from Asia. However, the findings on the direction of shock transmission is found to depend on the casual ordering of the variables in the VAR model. Hence, in the second paper that studies the linkages across different asset markets within the US, the authors adopted the Pesaran and Shin (1998) generalized variance decomposition framework which is invariant to the casual ordering of variables. This method was adopted by Guimaraes-Filho and Hong (2016) which examines how linkages in daily asset returns and volatilities in Asia vary over time, while Zhou et. al (2012) used the spillover indexes to investigate return volatility transmissions between China and world equity markets. In the rest of this section, we describe the methodology for computing the Diebold-Yilmaz spillover indexes.

To capture the relations between the return volatility of the stock indexes, we first estimate the following vector autoregressive (VAR) model:

$$v_t = \beta_0 + \sum_{k=1}^p \beta_k(L)v_{t-k} + \varepsilon_t$$

where v_t is a vector comprising the return volatilities of all the benchmark indexes. For each stock market, the relative importance of shocks to the return volatilities of other indexes to the return volatility of the home index is assessed through generalized variance decomposition analysis. We examine the variance decompositions at a horizon whereby the forecast error decompositions due to the various disturbances have stabilized. For the chosen horizon (H), each row (i) in the variance

decomposition table gives the proportion of forecast error variance due to innovations to the return volatility for the country listed in the column (j) which is denoted by $\theta_{ij}^g(H)$. As such, the diagonal terms reflect the importance of domestic shocks while the off-diagonal terms reflect the contributions from shocks to other indexes.

Since generalized variance decompositions allow for correlated shocks and thus do not typically sum to one for each row, the variance share is divided by the row sum to produce the normalized variance share:

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)}$$

The total spillover index $S(.,.)$ that measures overall cross-market spillovers is defined as the sum of all off-diagonal normalized variance shares, that is:

$$S(.,.) = \frac{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)}{N} \cdot 100$$

For each index, we can distinguish between receiving spillovers from other markets vis-a-vis transmitting spillovers to other markets by computing the two directional volatility spillover Indexes. The inward volatility spillover received by market i from other markets ($S(i,.)$) is the row sum of the off-diagonal normalized variance share, that is:

$$S(i,.) = \frac{\sum_{j=1}^N \tilde{\theta}_{ij}^g(H)}{N} \cdot 100$$

Conversely, the outward volatility spillover transmitted from market i to other markets ($S(.,i)$) is the column sum of the off-diagonal normalized variance share, that is:

$$S(.,i) = \frac{\sum_{j=1}^N \tilde{\theta}_{ji}^g(H)}{N} \cdot 100$$

The difference between the transmitting spillovers to other markets and receiving spillovers from other markets gives us index i 's net spillover index $S(i)$ that is:

$$S(i) = S(., i) - S(i, .)$$

To study the pattern of volatility transmissions in the region, we will compute these spillover indexes for the US, UK and the Asian bourses.

3 Return Volatilities and Spillover Indexes of Asian Markets

3.1 Data Description and Preliminary Statistics

We obtain data on the benchmark composite stock indexes of ten Asian countries, US and UK. They are the Shanghai Composite Index (China), Hang Seng Index (Hong Kong), Jakarta Stock Exchange Composite Index (Indonesia), Nikkei 225 (Japan), Korea Stock Exchange KOSPI Index (Korea), FTSE Bursa Malaysia KLCI Index (Malaysia), Philippines Stock Exchange PSEI Index (Philippines), Straits Times Index STI (Singapore), Taiwan Stock Exchange Weighted Index (Taiwan) and Stock Exchange of Thailand SET Index (Thailand), S&P 500 (US) and the FTSE 100 Index (UK). The inclusion of extra-regional bourses is important in light of the region's financial integration with global markets.⁴ All the local currency indexes are of daily frequency and drawn from the Bloomberg database. We note that carrying out the analysis on indexes that are expressed in US dollar will result in the confounding effect of foreign exchange market volatility.

⁴ To conserve degrees of freedom, we include only two extra-regional stock indexes namely S&P 500 and FTSE 100 indexes. However, these represent the New York Stock Exchange and the London Stock Exchange which are the two largest stock exchanges by country in terms of market capitalization. For robustness check, we repeat the analysis by replacing Taiwan's index with Germany's benchmark stock index DAX and obtain qualitatively similar results which are available from the author upon request.

The whole sample period spans 27 September 1999 to 30 May 2016. Due to the unavailability of data at an earlier time period for some countries in the study, we start our sample period in September 1999 which is after the Asian financial crisis. However, the time period does include the global financial crisis (henceforth, crisis). We split the sample period up into the following three sub-samples 27 Sep 1999 to 25 June 2007; 2 July 2007 to 28 Dec 2009 and 4 Jan 2010 to 30 May 2016 which we refer to as pre-crisis; crisis and post-crisis periods respectively. Comparisons across the sub-periods allow us to determine whether the extent of volatility spillovers is altered with the occurrence of the crisis.

To compute the weekly return volatility of an individual stock index, we obtain the following four stock index levels: highest (H), lowest (L), opening (O) and closing (C) price in the week. Following Alizadh et al. (2001), the weekly return volatility are computed as the square root of:

$$\begin{aligned}\tilde{\sigma}^2 = & 0.511(H_t - L_t)^2 - 0.019[(C_t - O_t)(H_t + L_t - 2O_t) - 2(H_t - O_t)(L_t - O_t)] \\ & - 0.383(C_t - O_t)^2\end{aligned}$$

Table 1 records the summary statistics of the return volatilities computed from the twelve benchmark stock indexes for the three sub-periods. The return volatilities all appear to exhibit a positive skew and have a leptokurtic distribution across all sample periods. As is expected, the mean and median volatility rose during the crisis period but declined after the crisis. In particular, the Chinese and Hong Kong markets were more volatile than the other regional bourses during the crisis. China continued to have the highest mean and median return volatility in the post-crisis period as well.

Table 1: Summary Statistics for Weekly Return Volatility⁵

	US	UK	JPN	HKG	CHN	SGP	KOR	TWN	IDN	MYS	PHL	THA
<i><u>Pre-crisis</u></i>												
Mean	1.93	2.00	2.35	2.26	2.56	1.07	3.13	2.71	2.49	1.60	2.01	2.45
Median	1.56	1.61	2.21	1.99	2.19	0.89	2.74	2.40	2.20	1.33	1.83	2.18
Std. Dev.	1.13	1.26	1.07	1.15	1.47	0.66	1.65	1.48	1.34	0.97	0.93	1.43
Skewness	1.58	2.03	0.98	1.86	1.72	1.53	1.57	1.76	2.16	1.80	1.53	3.20
Kurtosis	5.77	9.12	4.23	9.39	7.50	6.30	6.42	9.10	10.57	7.16	7.28	22.18
<i><u>Crisis</u></i>												
Mean	3.11	3.10	3.15	4.02	4.20	2.90	3.43	3.20	3.38	1.87	2.64	3.03
Median	2.45	2.58	2.66	3.50	3.98	2.26	2.85	2.92	2.70	1.61	2.28	2.43
Std. Dev.	2.20	1.92	2.26	2.52	1.83	2.10	2.33	1.57	2.21	1.11	1.46	1.71
Skewness	2.69	2.34	3.12	2.77	1.50	2.09	2.66	1.55	2.01	2.12	2.31	1.61
Kurtosis	11.72	9.69	14.67	14.09	7.52	7.74	11.55	6.42	7.56	9.38	11.08	5.52
<i><u>Post-crisis</u></i>												
Mean	1.67	1.85	2.18	1.99	2.53	1.42	1.68	1.65	1.93	1.09	1.76	1.88
Median	1.42	1.66	1.89	1.80	2.16	1.22	1.43	1.42	1.62	0.94	1.55	1.61
Std. Dev.	0.98	1.00	1.24	1.03	1.53	0.74	0.94	0.86	1.19	0.64	1.03	1.05
Skewness	2.25	1.95	3.42	2.21	2.55	1.62	2.82	2.39	2.26	2.51	2.64	2.58
Kurtosis	10.62	8.74	24.42	12.35	12.41	6.52	16.58	12.65	9.82	12.68	14.23	13.13

3.2 Spillover Indexes of Return Volatilities

We model the return volatilities of the twelve benchmark indexes using a vector autoregressive (VAR) model with 4 lags⁶ over the full sample period and the three sub-periods. For

⁵ In this and the following tables and charts, we use JPN, CHN, HKG, IDN, KOR, MYS, PHL, SGP, TAI and THA to represent Japan, China, Hong Kong, Indonesia, Korea, Malaysia, the Philippines, Singapore, Taiwan and Thailand respectively.

⁶ For robustness checks, we repeat the analysis using a VAR with 2 lags as well as include the VIX index which is the Chicago Board Options Exchange Market Volatility Index as an exogenous variable. The results obtained, which are available from the author upon request, are qualitatively similar.

each time period, the normalized variance shares at the 10-week horizon are used to compute the total spillover index $S(.,.)$. The total volatility spillover index over the full sample period is high, with 66.2% of forecast variance decomposition due to cross-market spillovers, suggesting large international transmission of financial shocks in the region. In sub-sample analysis, the total volatility spillover index rose from 51.7% in the pre-crisis period to 78.9% during the crisis. The jump in the total volatility spillover index from pre-crisis to crisis period is expected as it reflects the sharp falls across the bourses during the crisis. While we observe a decline in the total volatility spillover index post crisis, the index level remained elevated at 68.1%. This is much higher than the pre-crisis level, suggesting that the strengthening of volatility spillovers is not a temporary surge during the crisis but persisted after the crisis.

Concomitantly, we see a decline in the role of domestic shocks not only during the crisis but also after the crisis. Table 2 records the domestic variance shares which, with the sole exception of Japan, fell in the crisis and post-crisis periods as compared to the pre-crisis period. It is perhaps not surprising that all the individual Asian bourses experienced higher volatility transfers with external stock markets post crisis in view of the greater uncertainty in the economic environment after the crisis.

Table 2: Domestic Variance Share in Sub-samples (%)

	JPN	HKG	CHN	SGP	KOR	TWN	IDN	MYS	PHL	THA
<i>Pre-crisis</i>	41.85	38.10	77.37	35.88	39.24	46.74	56.43	38.86	61.06	58.07
<i>Crisis</i>	13.08	13.07	51.57	17.00	13.11	22.57	17.42	23.93	21.21	20.97
<i>Post-crisis</i>	44.62	25.50	53.75	24.75	27.36	25.53	29.79	32.43	28.68	37.22

Turning to directional spillovers, we record in Table 3 the inward spillover index $S(i.,.)$, outward spillover index $S(.,i)$ and the net spillover index $S(i)$ of the individual stock markets. It is clear from Table 3 that the US and UK bourses persistently transmit shocks to the Asian stock

markets so that their net spillover indexes remain positive in all sub-periods. Nevertheless, inward spillovers to the extra-regional equity markets of US and UK increased in both the crisis and post-crisis periods, relative to the pre-crisis period. This concurs with the findings in IMF (2016) that stock markets in the advanced economies have become more susceptible to spillovers from emerging markets.

Table 3: Directional Spillover Indexes (%)

	US	UK	JPN	HKG	CHN	SGP	KOR	TWN	IDN	MYS	PHL	THA
<u>Pre-crisis</u>												
$S(i,.)$	4.93	4.58	4.85	5.16	1.89	5.34	5.06	4.44	3.63	5.10	3.24	3.49
$S(.,i)$	8.02	7.54	3.63	7.49	1.05	5.03	5.40	4.40	2.54	2.78	1.62	2.21
$S(i)$	3.09	2.96	-1.22	2.33	-0.84	-0.31	0.34	-0.04	-1.09	-2.31	-1.62	-1.29
<u>Crisis</u>												
$S(i,.)$	6.39	7.01	7.24	7.24	4.04	6.92	7.24	6.45	6.88	6.34	6.57	6.59
$S(.,i)$	11.52	9.17	6.01	6.91	1.27	6.90	5.65	8.23	7.29	4.36	5.86	5.72
$S(i)$	5.14	2.16	-1.24	-0.33	-2.77	-0.02	-1.59	1.78	0.41	-1.98	-0.70	-0.87
<u>Post-Crisis</u>												
$S(i,.)$	6.09	6.10	4.61	6.21	3.85	6.27	6.05	6.21	5.85	5.63	5.94	5.23
$S(.,i)$	6.38	8.52	2.17	5.91	2.55	9.51	7.70	6.15	5.90	3.58	4.57	5.11
$S(i)$	0.29	2.42	-2.45	-0.30	-1.31	3.24	1.65	-0.05	0.05	-2.05	-1.38	-0.12

The stronger volatility transmissions to the stock markets in US and UK could be due to increased participation of the Asian economies in the global supply chains so that economic news in the region affects the advanced economies' firms that are exporting to or have subsidiaries in Asia. Besides, there was a surge of capital inflow to the region from the mid-2000s arising from the low extra-regional interest rate environment. The increased presence of advanced economies' investors in the Asian equity markets served to strengthen the portfolio rebalancing channel that heightened financial market spillovers as well. Fukuda and Tanaka (2016) found that after the global financial crisis, advanced countries' bourses were more responsive to shocks in emerging Asia's

manufacturing sector compared to shocks in their financial sector. They inferred that real linkages such as trade integration play a more important role relative to financial linkages in increasing the susceptibility of advanced countries' stock markets to volatility transfers from emerging Asia.

Focusing on the Asian markets, we see from Table 3 that the directional spillover index from others rose for all countries when we move from pre-crisis to crisis period. With the sole exception of Japan, the inward spillover index remained higher in the post-crisis period relative to the pre-crisis period. Prior to the crisis, the stock market in China experienced the lowest level of spillovers from other markets as it was shielded by restrictions to foreign participation in the Chinese market. The three regional bourses in China, Indonesia and the Philippines which had the lowest inward spillover index prior to the crisis recorded the most dramatic percentage increase in the index post crisis.

Nonetheless, the post crisis inward spillover index levels in these three markets were still lower than those in the equity markets of Hong Kong, Singapore, Korea and Taiwan. This is because the latter group of bourses remained more open than those China, Indonesia and the Philippines after the crisis, as revealed by Fernández et al. (2015)'s de-jure measure of stock market openness. The latter is an index that takes a value between value 0 and 1, with a lower value reflecting greater openness in stock market transactions. The 2013 openness index for China, Indonesia and the Philippines are 1, 0.75 and 1 respectively; whilst those for Hong Kong, Singapore and Korea are 0, 0 and 0.25 respectively.⁷

Turning to outward volatility transfers, we similarly observe an increase in transmissions from individual Asian markets to external markets with the occurrence of the crisis. The outward spillover index remained higher in the post-crisis period relative to the pre-crisis period for all the Asian stock markets except the Japanese and Hong Kong bourses. The results suggest that the Asian

⁷ Unfortunately, index data for Taiwan is not available.

bourses are becoming more important emitters of financial shocks. Hong Kong (Singapore) recorded the highest outward spillover index pre (post) crisis. This is unsurprising as these two countries are international financial centers with substantially higher stock market capitalization to GDP ratios compared to the other Asian markets. The stock markets in Hong Kong and Singapore serve as a conduit for international transmissions, transferring volatility to other countries.

On a net basis, the Asian markets tended to receive volatility transfers from other markets prior to the crisis. However, the net spillover index became less negative for Malaysia, the Philippines and Thailand, and turned positive or became more positive for Singapore, Korea and Indonesia when we compare post- to pre-crisis period. This is consistent with the findings in Guimaraes and Hong (2016) that the Asian bourses are growing in importance as net shock givers. By contrast, the Japanese bourse is a net receiver of volatility transfers in both pre- and post-crisis periods and its net spillover index became more negative after the crisis. The net spillover index for Japan is the most negative of all countries in the sample in the post-crisis period. A possible explanation for the declining role played by Japan as a shock emitter is the relatively slower growth in the market capitalization of its stock exchange. According to data from the World Bank, domestic market capitalization in Japan grew only by 10% from USD 4.5 trillion in 1999 to USD 4.9 trillion in 2015. In comparison, market capitalization for the Asia-Pacific region as a whole rose by over 200% from USD 6.7 trillion to USD 21.6 trillion over the same period.

4 Relative Influence of Major External Stock Markets

The heightened sensitivity of Asian bourses to volatility transmissions from external markets post crisis raises the question of whether there is a change in the relative level of influence exerted by the major external markets of US, Japan and China. The US and Japanese equity markets have

long been integrated with world markets and can be expected to exert a significant influence on Asian markets. By contrast, capital controls in China restricts the interactions of Chinese stock markets with external bourses. Nonetheless, the Shanghai bourse driven by the increase in the number of new listings recorded huge growth in domestic market capitalization to rank fifth in the world in 2015. Some studies including Glick and Hutchinson (2013) and Arslanalp et. al (2016) found that stock returns in Asia have become more correlated with Chinese stock price movements in spite of capital controls in China. Hence, we investigate whether the pole of influence for the stock markets in the region has shifted between the US, Japan and China in terms of weekly stock return volatilities.

To assess how the level of association between the return volatilities of individual Asian bourses and those in the major markets in the US, Japan and China have changed over time, we run following country-specific rolling regression for each Asian stock market j :

$$v_{it}^j = \gamma_i + \delta_{USi} v_{it}^{US} + \delta_{JPi} v_{it}^{JP} + \delta_{CHi} v_{it}^{CH} + \sum_{k=1}^q \beta_k v_{it-k}^j + \alpha VIX_{it} + \varepsilon_{it}$$

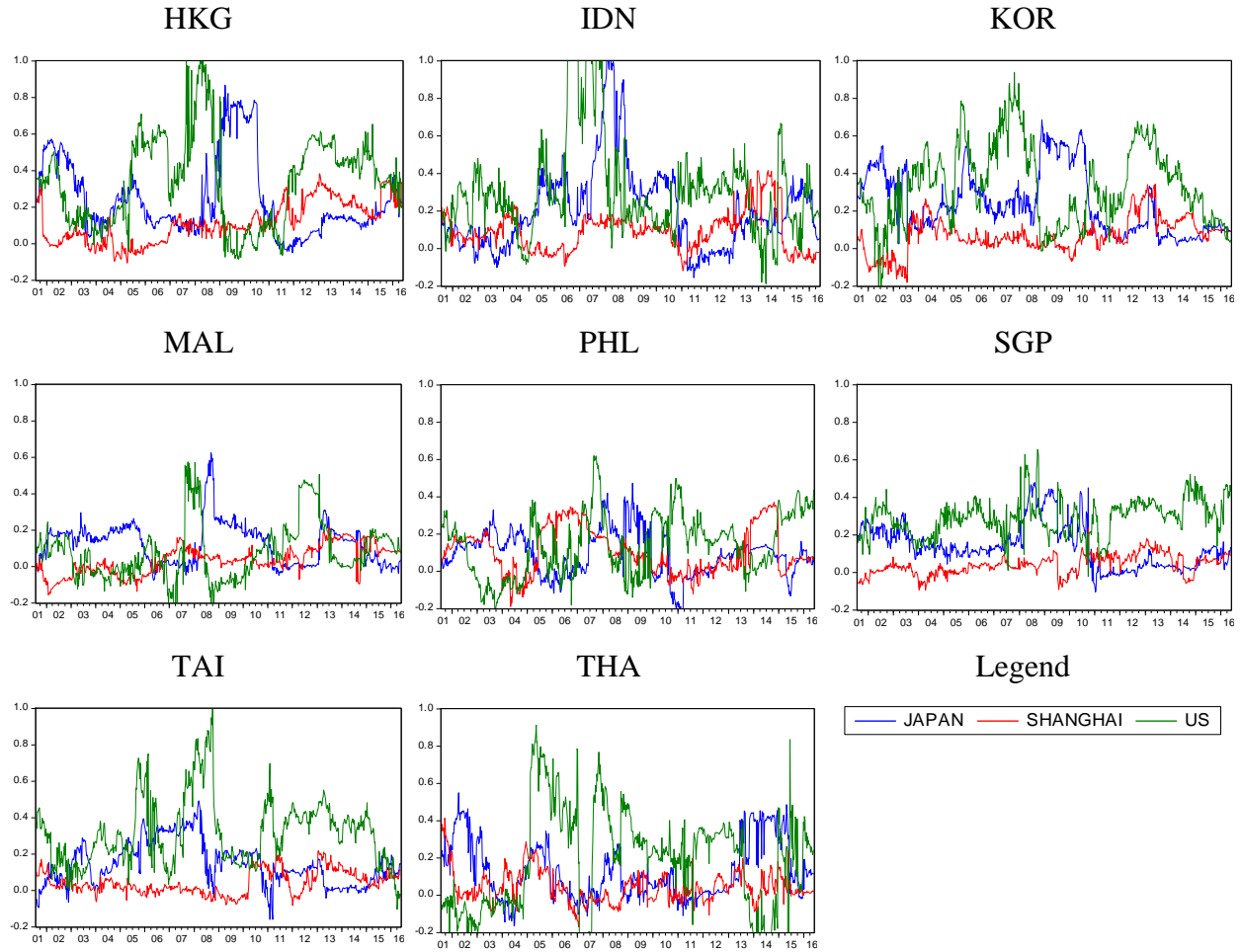
$$\sigma_{it} = \alpha_{0i} + \alpha_{1i} \varepsilon_{it-1}^2 + \beta \sigma_{it-1}^2$$

where $\varepsilon_{it} \sim N(0, \sigma_{it}^2)$ and the v_{it} terms denote the return volatility of an index at time t estimated for the i th window. The superscripts j , US , JP and CH denote an Asian, the US, Japanese and Chinese stock index respectively. While advanced markets are now more susceptible to developments in emerging markets as a whole, the effect from any single Asian bourse is not likely to be significant since the individual Asian bourses are too limited in size to exert a meaningful influence on any of the three major markets. Hence, simultaneity bias in the country specific regressions is likely to be negligible. In addition, feedback effects are more likely to occur at a higher frequency such as with daily volatilities so that these will be recorded as contemporaneous effect with weekly volatilities.

We include lagged dependent variables to capture the persistence in the volatility series. As in the case of the VAR models, the number of terms q is kept at four for all the country-specific regressions. The *VIX* term is the Chicago Board Options Exchange Market Volatility Index which measures the implied volatility of S&P 500 index options and is commonly used to represent international investors' appetite for risks. We include the *VIX* index in our rolling regressions to capture common shocks to the different bourses. A GARCH(1,1) process turns out to be highly significant for all cases. We use a backwards 100-week fixed window for the rolling regressions so that the regression is estimated with approximately two years of data for each window.

The magnitude of the regression coefficients δ_{USi} , δ_{JPi} and δ_{CHi} reflect the extent which volatilities in the major markets of US, Japan and China are associated with volatility in the individual Asian bourse over time. Unlike time varying spillover indexes, these coefficients in the rolling regressions capture dynamically both the direct and indirect effects of advanced market volatilities on individual Asian stock market volatility. Figure 1 displays the time varying coefficients of rolling regressions for each Asian stock market. With the exception of Malaysia and the Philippines, we see from Figure 1 a general pattern of relative dominance of the US stock index over the Japanese and Chinese stock indexes over the entire sample period. This is consistent with our findings in the previous section that the outward spillover index of US is larger than that of Japan and China in all three sub-periods.

Figure 1: Rolling Regression Coefficients



Prior to the crisis, volatility of the Asian bourses appears to be more affected by the gyrations in the Japanese stock index compared to the Chinese stock index. Exceptions are the Philippines and Thailand where there appear to be no clear dominance between these two major indexes. However, the strength of correlation in return volatilities between the Japanese and Asian bourses became more similar to that between the Chinese and Asian markets after the crisis. In fact, the Japanese stock index was less influential than the Chinese stock index for Hong Kong post crisis. Again, this is similar to our earlier results that the outward spillover index of Japan is higher than that of China in all sub-periods but the difference narrowed considerably after the crisis.

Indeed, we observe a general tightening of correlations in return volatilities between the Chinese stock market and the Asian bourses after the crisis.⁸ Exceptions are the stock markets in the Philippines and Thailand which experienced similar correlation levels in return volatilities with the Chinese bourse before and after the crisis. Table 4 records the difference between China and Japan in terms of their mean rolling coefficients, average over the two periods before and after 2010. Apart from the Philippines and Thailand, the difference in the average coefficients between China and Japan is negative before 2010 but shrank in magnitude to almost zero after 2010.⁹ Such a finding is not unexpected given our earlier results that the outward spillover index for China jumped by 96.2% as we go from pre- to post-crisis period as compared with the corresponding 33.6% drop for Japan.

Table 4: Difference in Average Rolling Coefficients between China and Japan

	HKG	SGP	KOR	TWN	IDN	MYS	PHL	THA
<i>Pre-2010</i>	-0.25	-0.18	-0.28	-0.18	-0.18	-0.15	0.00	-0.07
<i>2010 onwards</i>	0.04	0.01	-0.03	0.00	-0.03	0.00	0.03	-0.10

A rising trend in China's rolling regression coefficient is most evident in the case of Hong Kong (see Figure 1). Financial ties between Hong Kong and China strengthened significantly during the last decade as China embarked on liberalization of domestic financial markets and capital controls. In particular, initiatives such as Connect scheme and cross equity listings created new channels of volatility transmission. The jump in inter-linkages between the equity markets in the two

⁸ We note this result is not just driven by the isolated events of 24 August 2015 and 4 Jan 2016 which were highlighted in the introduction section. These events only affect the rolling regressions from 24 August onwards. We observe from Figure 1 that, with few exceptions, the post crisis rise in the coefficient for China began way before that.

⁹ The results are not inconsistent with the findings of Arslanalp et al. (2016) that financial spillovers from China to the Asian markets in terms of asset returns of equity have risen to the level for Japan.

countries can also be seen from Hong Kong's variance share in the three sub-samples. Shocks to China's equity markets explain for less than 1% of Hong Kong's equity market volatility prior to and during the crisis and but this went up to over 7% after the crisis. As China continues to privatize its state-owned enterprises, deregulate its financial markets, open its financial account and internationalize the RMB, its financial channels with the Asian countries will become more important. This will lead to greater intra-regional volatility spillovers going forward.

5 Conclusion

International linkages among global financial markets have been strengthening over time, aided by better communications, advancement in trading and information technology, and market liberalization. The partial opening of the China financial markets to foreign participation and the gradual shift towards market-determined exchange rates also increased their interactions with world markets. How have these developments affected the pattern of volatility transfers in Asian stock markets? To investigate, we apply Diebold & Yilmaz (2012) framework for measuring spillovers across asset markets that uses the generalized variance decompositions from a vector autoregressive model. Diebold-Yilmaz spillover indexes are computed for weekly return volatilities based on daily benchmark stock indexes of US, UK and ten Asian countries namely, China, Hong Kong, Indonesia, Japan, Korea, Malaysia, the Philippines, Singapore, Taiwan and Thailand. The analysis was carried out over for the period September 1999 to May 2016 as well as on sub-periods to facilitate pre-versus post-crisis comparisons.

We found the rise in volatility transfers is not a temporary surge due to contagion during the global financial crisis, but reflects a more permanent increase in volatility transmissions. Compared to the pre-crisis period, all the individual Asian bourses experienced higher volatility transfers with

external stock markets post crisis as there was greater uncertainty in the economic environment. Directional spillover indexes reveal both inward and outward volatility transmissions have intensified for the individual Asian stock markets, not just during the crisis but also after the crisis. However, we found the level of inward volatility transfers still varies across the individual Asian bourses according to their degree of openness. Meanwhile, the rise in outward volatility transfers suggests that the Asian bourses are becoming more important emitters of financial shocks. Indeed, as we move from the pre-crisis to post-crisis period, the net spillover index for most of the Asian bourses either became less negative or turned positive. In summary, our study not only confirms the overall qualitative results for daily volatilities shown in Guimaraes-Filho and Hong (2016) carry over to weekly volatilities, but also provides evidence that the susceptibility of an individual Asian stock market to inward volatility shocks transmission from other markets is linked to its degree of openness.

Finally, an examination of the relative influence of the financial shocks originating from the major stock markets of US, Japan and China using rolling regressions review the pole of influence has somewhat shifted. We show, in terms of volatility linkages, a general pattern of relative dominance of the US stock market over the Japanese and Chinese bourses over the entire sample period. However, the linkages in return volatilities between the Asian and Japanese (Chinese) bourses tended to weaken (strengthen) with the onset of the crisis. In fact, the correlation of Asian stock volatilities with Chinese stock volatilities rose to its level with Japan but remained lower than its level with the US. In general, we find the level of influence on Asian stock markets from the Chinese bourse, in terms of volatility linkages, has risen to that from the Japanese bourse but remains lower than that from the US stock market. This finding concurs with recent studies that show greater sensitivity of Asian bourses to China's stock price fluctuations. As China continues to

privatize its state-owned enterprises, liberalize its financial markets, open its financial account and internationalize the RMB, its financial channels with the Asian countries will become more important. This will likely lead to greater intra-regional volatility spillovers going forward.

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